

disclosed embodiments of the invention will now be discussed in comparison to the applied reference. Specific distinctions between the pending claims and the applied references will be discussed after the discussion of the disclosed embodiments and the applied reference. This discussion of the differences between the disclosed embodiments and applied reference does not define the scope or interpretation of any of the claims.

One embodiment of the present invention is discussed with reference to Figures 7-10 in which an interposing layer 52 such as a tungsten nitride layer 52 is formed between a conductive plug 46 formed in a via 44 and a conductive line material 48 formed in a trench or container 50. The tungsten nitride layer 52 enhances the electrical contact between the line material and the plug, promotes adhesion of the line material within the container 50, prevents or slows the diffusion of materials across the tungsten nitride layer boundary, or serves some other purpose. As previously described, the tungsten nitride layer 52 may associate with oxygen after it is formed and subsequent thermal processes may result in the formation of an oxide layer 54 formed between the tungsten nitride layer 52 and the line material 48. Because the oxide layer 54 is an insulator, this layer will adversely affect the electrical connection between the line material 48 and the plug 46. By exposing the tungsten nitride layer 52 to an oxygen-inhibiting agent or a reducing atmosphere prior to formation of the line material 48, the thickness of the oxide layer 54 is reduced to a thickness of less than 10 angstroms or entirely eliminated as illustrated respectively in Figures 9 and 10. Thus, in all embodiments a conductive layer is exposed to an oxygen-inhibiting agent or reducing atmosphere prior to another layer being formed on the conductive layer to thereby reduce an ability of the conductive material to associate with oxygen.

As described in the specification, the tungsten nitride layer 52 or other conductive layer may be treated in a plasma such as an N_2 and H_2 plasma, an NH_3 plasma, or an N_2 plasma. See page 6, lines 13-30 and page 7, lines 1-19. Furthermore, the conductive layer may be treated in a nitrogen-free gas, such as a plasma treatment including H_2 or other gases such as diborane B_2H_6 , PH_3 , CH_3SiH_3 , $(CH_3)_3Si-Si(CH_3)_3$, HMDS, CF_4 , CHF_3 , HCL , BCl_3 , and silane SiH_4 , and any combinations of these gases, as described on page 7, lines 25-30, page 8, lines 1-16, and page 9, lines 1-12. As will be appreciated by those skilled in the art, the use of a plasma treatment enables energy of ions forming the plasma to be closely controlled to thereby more precisely

treat the tungsten nitride layer as desired. Moreover, the other nitrogen-free gases provide beneficial treatment of the conductive layer when compared to nitriding of the layer by exposure to a nitrogen containing gas and the associated heat treatment.

Another embodiment of the present invention is illustrated in Figures 4 and 5 that depict an in-process semiconductor device. As mentioned in the specification, for the purposes of explanation the in-process semiconductor device is assumed to be a capacitor in the process of being constructed. In Figure 4, the capacitor includes a first conductive layer or 24, which may be formed from hemispherical silicon grain (HSG), formed over a substrate 22, and a dielectric 26 formed on the first conductive layer. In the examples of Figures 4 and 5, the dielectric 26 is formed from tantalum pentoxide Ta_2O_5 . A second conductive layer 28 formed from tungsten nitride WN_x is then formed on the dielectric 26. The tungsten nitride layer 28 has a tendency to associate with oxygen, particularly if that layer is exposed to oxygen prior to a third conductive polysilicon layer 30 being formed on the tungsten nitride layer 28. During subsequent processing of the capacitor, the oxygen contained in the tungsten nitride layer 28 can combine with silicon from the polysilicon layer 30 to form an unwanted silicon dioxide layer 36 between the tungsten nitride layer 28 and the polysilicon layer 30. For example, a thermal process step such as the formation of a borophosphosilicate glass (BPSG) layer 34 over the polysilicon layer 30, which of course occurs after the formation of the polysilicon layer 30, may cause a reaction between the polysilicon layer 30 and the oxygen in the tungsten nitride layer 28 and thereby form the silicon dioxide layer 36.

Ideally, the HSG layer 24 forms a first plate of the capacitor, the tantalum pentoxide 26 forms the dielectric of the capacitor, and the tungsten nitride layer 28 and polysilicon layer 30 form the second plate of the capacitor. With the formation of silicon dioxide layer 36, however, the capacitor now includes a first capacitor corresponding to the HSG layer 24, tantalum pentoxide 26, and tungsten nitride layer 28, and a second capacitor in series with the first capacitor, with the second capacitor corresponding to the tungsten nitride layer 28, silicon dioxide layer 36, and polysilicon layer 30. These first and second capacitors connected in series have a combined capacitance that is less than that of the ideally formed capacitor. As will be understood by those skilled in the art, the thickness of the silicon dioxide layer 36 affects the value of the combined capacitance.

The Kamiyama Patent discloses a method of forming a capacitor having a reduced dielectric thickness while at the same time having improved leakage current characteristics. As discussed in the background, tantalum oxide has a high dielectric constant and is thus used to form capacitors having increased capacitance values. In forming such capacitors, a tantalum oxide layer is formed on a polysilicon electrode and subjected to a heat treatment to improve the leakage current characteristics of the tantalum oxide layer. This heat treatment results in a native oxide layer between the tantalum oxide layer and polysilicon electrode increasing in thickness and thereby decreasing the capacitance of the capacitor since the dielectric constant of the native oxide is lower than the dielectric constant of the tantalum oxide layer.

Figures 4A-D are cross-sectional views illustrating sequential steps of the fabrication of a capacitor including a tantalum oxide film having improved leakage current characteristics that results in a native oxide layer having a reduced thickness so that the formed capacitor has an increased capacitance value and lower leakage current. A polysilicon layer 3 forms a low electrode of the capacitor and a silicon nitride film 24 is formed on the polysilicon electrode using ammonia gas. A tantalum oxide film 5 is deposited on the silicon nitride film 24 and converted into a densified tantalum oxide film 5a comma with a titanium nitride film six thereafter been formed on this densified tantalum oxide film to form an upper electrode 6. None of the embodiments of Kamiyama expose first conductive layer to a material, such as diborane or phosphine, to reduce an ability of the first conductive layer to associate with oxygen, and thereafter form a second conductive layer on the first conductive layer. In contrast, Kamiyama deals with the formation of a capacitor including a tantalum oxide, the capacitor having an increased capacitance value and lower leakage current.

The Lee patent is directed to a capacitor having a dielectric film formed from a high dielectric material between upper and lower electrodes. Figure 1 illustrates a capacitor structure including a lower polysilicon electrode 18 having an amorphous silicon carbide (SiC) layer formed thereon, with a dielectric layer 26 being formed on the silicon carbide layer and an upper silicon carbide layer 28 being formed thereon. An upper polysilicon electrode 30 is then formed on the upper silicon carbide layer 28, with the layers 28 and 30 forming an upper plate electrode of the capacitor. The silicon carbide layers prevent the migration of oxygen between the dielectric layer 26 and the lower polysilicon electrode 18 and upper polysilicon electrode 30.

In the capacitor of Figure 4, the thickness of the silicon dioxide layer 36 is greatly reduced by exposing the tungsten nitride layer 28 to an oxygen-inhibiting agent prior to the formation of the polysilicon layer 30 to thereby greatly reduce the association of the tungsten nitride layer with oxygen. The silicon dioxide layer 36 in the embodiment of Figure 4 is less than 10 angstroms thick due to the oxygen-inhibiting agent, while in a conventional capacitor shown in Figure 3 the silicon dioxide layer 36 is about 10-40 angstroms thick. In the capacitor of Figure 5, the exposure of the tungsten nitride layer 28 to the oxygen-inhibiting agent eliminates the formation of the silicon dioxide layer 36 altogether.

The oxygen-inhibiting agent may be an N_2 and H_2 plasma, with the tungsten nitride layer 28 ideally being exposed to this plasma prior to exposing tungsten nitride layer to an atmosphere associated with the formation of the polysilicon layer 30 or prior to exposing the tungsten nitride layer to oxygen. As described in the specification, it is believed the exposure of the tungsten nitride layer 28 to the N_2 and H_2 plasma or any of the other oxygen-inhibiting agents stuffs the tungsten nitride layer grain boundaries with nitrogen or otherwise passivates the tungsten nitride layer, making the bonds at the grain boundaries less active and less likely to associate with oxygen. It should be noted that even if the tungsten nitride layer 28 is exposed oxygen, the layer may thereafter be exposed to a reducing atmosphere, such as silane gas SiH_4 , prior to formation of the polysilicon layer 30 to thereby reduce the oxygen content of the tungsten nitride layer 28 and reduce the thickness of any silicon dioxide layer 36 thereafter formed.

In another embodiment of the present invention discussed with reference to Figure 6, a first conductive layer such as a tungsten nitride layer 128 is deposited over a substrate 122 and a dielectric layer 126, such as a tantalum pentoxide layer, is deposited over the tungsten nitride layer. In this situation, the deposition of the tantalum pentoxide layer 126 may cause the tungsten nitride layer 128 to incorporate oxygen, reducing the capacitance of a capacitor including the tungsten nitride layer and tantalum pentoxide layer. Accordingly, in this embodiment of the invention, the tungsten nitride layer 128 is exposed to a N_2 and H_2 plasma or other oxygen-inhibiting agent before depositing the tantalum pentoxide layer 126. As previously described, the N_2 and H_2 plasma passivates the tungsten nitride layer 128 to thereby prevent oxygen from being incorporated within the tungsten nitride layer.

Lee does disclose exposing a first conductive layer to materials such as diborane, phosphine, hydrochloric acid, and boron trichloride to reduce an ability of the first conductive layer to associate with oxygen, and thereafter forming a second conductive layer on the first conductive layer.

Amended claim 54 recites a method of forming a semiconductor device including providing a first conductive layer and preventing at least some oxygen from migrating in relation to said first conductive layer by exposing the first conductive layer to a material selected from the group consisting of diborane, phosphine, hydrochloric acid, and boron trichloride. A second conductive layer is provided on the first conductive layer after exposure of the first conductive layer to the material selected from the group. Neither Lee nor Kamiyama discloses or suggests exposing a first conductive layer to a material selected from the group consisting of diborane, phosphine, hydrochloric acid, and boron trichloride and thereafter providing a second conductive layer. The combination of elements recited in amended claim 54 is thus allowable. Dependent claims 55 and 56 are allowable for at least the same reasons as claim 54 and because of the additional limitations added by these claims.

The specification has been amended to include the patent number corresponding to an application number set forth in the specification. This amendment adds no new matter.

All pending claims are in condition for allowance, and favorable consideration and a Notice of Allowance are respectfully requested. The Examiner is requested to contact the undersigned at the number listed below for a telephone interview if, upon consideration of this amendment, the Examiner determines any pending claims are not in condition for allowance. The undersigned also requests the Examiner to direct all future correspondence to the address set forth below in the event the Examiner shows a different correspondence address for the attorney of record.

Attached hereto is a marked-up version of the changes made to the specification and claims by the current amendment. The attached page is captioned "Version with Markings to Show Changes Made".

Respectfully submitted,

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PFR:asw

Enclosures:

Postcard

Fee Transmittal Sheet (+ copy)

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

In the Specification:

Paragraph beginning at line 4 of page 8 has been amended as follows:

Still other gases include diborane (B_2H_6); phosphine (PH_3); and carbon-silicon compounds such as methylsilane (CH_3SiH_3) and hexamethyldisilane ($(CH_3)_3Si-Si(CH_3)_3$); and hexamethyldisilazane (HMDS). Additional alternate embodiments of the current invention use hydrazine (N_2H_4), monomethylhydrazine, carbon tetrafluoride (CF_4), CHF_3 , HCl , and boron trichloride (BCl_3), which are also useful in passivating dielectrics, as addressed in copending application 09/114,847, now issued as U.S. Patent No. 6,201,276 B1. Also included are mixtures of any of the gases or types of gases described above. Exemplary non-plasma process parameters using these other gases include a flow rate of about 2 sccm to about 400 sccm for these gases; a flow rate of about 50 sccm to about 100 sccm for an inert carrier gas such as He or Ar; a temperature ranging from about 150 to about 600 degrees Celsius, a pressure ranging from about 50 millitorr to about 1 atmosphere (760 torr); and a process time ranging from about 50 to about 500 seconds. Again, one skilled in the art is aware that these parameters can be altered to achieve the same or a similar process.

In the Claims:

Claim 54 has been amended as follows:

54. (Amended) A method of forming a semiconductor device, comprising:
providing a first conductive layer; [and]
preventing at least some oxygen from migrating in relation to said first conductive layer by exposing the first conductive layer to a material selected from the group consisting of diborane, phosphine, hydrochloric acid, and boron trichloride; and
providing a second conductive layer on the first conductive layer after exposure of the first conductive layer to the material selected from the group.